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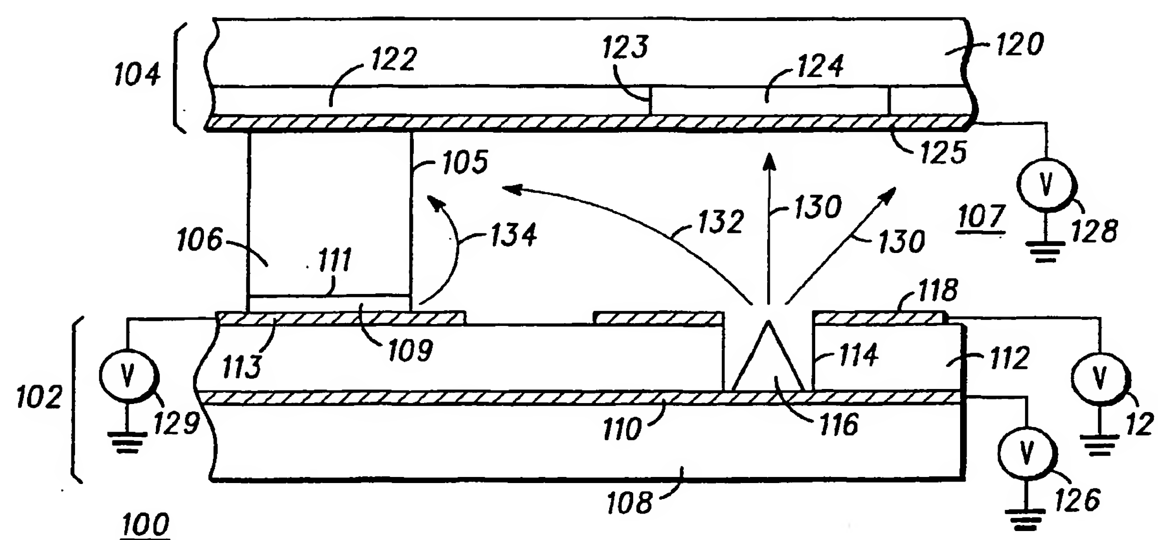
(54) Title: FIELD EMISSION DISPLAY HAVING DISCHARGE ELECTRON EMITTER



(57) Abstract: A field emission display (100, 200, 300, 400) includes a spacer (106) defining a surface (105); a charging electron emitter (116); an anode (125) disposed to receive electrons (130) emitted by charging electron emitter (116), wherein anode (125) is designed to be operated at an operating voltage greater than about 1000 volts relative to charging electron emitter (116), and wherein a portion of electrons (130) emitted by charging electron emitter (116) for reception by anode (125) cause electrostatic charging of surface (105) of the spacer (106); and a discharge electron emitter (109, 209, 409) designed to discharge charged spacer surface (105) while the voltage at anode (125) is equal to the operating voltage. Discharge electron emitter (109, 209, 409) is disposed intermediate spacer (106) and charging electron emitter (116) and is preferably made from carbon nanotubes.

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FIELD EMISSION DISPLAY HAVING DISCHARGE ELECTRON EMITTER

Field of the Invention

The present invention pertains to the area of field emission displays and, more particularly, to field emission displays having dielectric spacers, which maintain the separation distance between a cathode plate and an anode plate of the field emission display.

Background of the Invention

Field emission displays, which have dielectric spacers for maintaining the separation distance between a cathode plate and an anode plate of the display, are known in the art. It is recognized in the art that the surfaces of the dielectric spacers can become electrostatically charged during the operation of the display. The electrostatically charged surfaces of the dielectric spacers can cause problems, such as the "visibility" of the spacer structures to the viewer of the display. That is, the charged surfaces cause electrons, which are directed toward phosphors, to be attracted toward the charged surfaces and away from the phosphors. In this manner, an undesirable gap is formed in the display image at the location of each spacer.

It is known in the art to neutralize the charged spacer surfaces from time to time during the operation of the display. For example, it is known in the art to use the electron emitters, which are used for activating the phosphors, to provide discharging electrons for discharging the charged spacer surfaces. The prior art teaches that the discharging electrons are provided while the voltage at the phosphors is reduced from a display mode value. The display mode value is the value used for activating the phosphors. Although these discharging electrons are useful for discharging the spacer surfaces, some of the electrons can be attracted toward non-spacer surfaces. When the deviant electrons strike non-spacer surfaces, they can cause outgassing of contaminant species, which can cause deterioration of the emission characteristics of electron emitters.

Another problem with this prior art scheme is that considerable energy is expended to pull down and pull back up the anode voltage. For example, the anode voltage used during the display mode, during which the display image is created, can be greater than 1000 volts. It is known to reduce the anode voltage to less than about 400 volts during the discharge mode, during which the spacers are discharged.

Accordingly, there exists a need for an improved field emission display, which provides a means for discharging spacers that does not require a reduction in the anode voltage and that reduces the rate of outgassing below that of the prior art.

Brief Description of the Drawings

FIG.1 is a cross-sectional, partial view of a field emission display having a discharge electron emitter, which is an edge emitter, in accordance with a preferred embodiment of the invention;

FIG.2 is a cross-sectional, partial view of a field emission display having a discharge electron emitter, which is a surface emitter, in accordance with another embodiment of the invention;

FIG.3 is a cross-sectional, partial view of a field emission display having a discharge electron emitter, which is caused to emit by a triode configuration of electrodes, in accordance with yet another embodiment of the invention; and

FIG.4 is a cross-sectional, partial view of a field emission display having a discharge electron emitter, which is a Spindt tip emitter that is caused to emit when a charging electron emitter is caused to emit.

It will be appreciated that for simplicity and clarity of illustration, elements shown in the drawings have not necessarily been drawn to scale. For example, the dimensions of some of the elements are exaggerated relative to each other. Further, where considered appropriate, reference numerals have been repeated among the drawings to indicate corresponding elements.

Description of the Preferred Embodiments

The invention is for a field emission display, which can be operated at high voltages while maintaining invisibility of dielectric spacers. Spacer invisibility is achieved by providing discharge electron emitters. The discharge electron emitters are designed to discharge electrostatically charged spacer surfaces while the voltage at the anode is equal to the operating voltage (e.g., greater than about 1000 volts relative to the charging electron emitters). That is, the anode voltage need not be reduced to achieve spacer invisibility, thereby realizing improved power consumption requirements over the prior art. Preferably, the discharge electron emitters are made from carbon and define a diode configuration in conjunction with the anode of the display. Preferably, the discharge electron emitters are disposed sufficiently proximate to the spacer, such that the electrons emitted by the discharge electron emitter can cause discharging of the charged spacer surface.

FIG.1 is a cross-sectional, partial view of a field emission display (FED) 100 having a discharge electron emitter 109, which is an edge emitter, in accordance with a preferred embodiment of the invention. Although the FIGs. described herein are directed toward display devices, the scope of the invention is not limited to display devices. Rather, the invention is useful for discharging spacers and other charged structures in any type of field emission device having such structures.

FED 100 includes a cathode plate 102 and an anode plate 104. Cathode plate 102 is spaced apart from anode plate 104 by a spacer 106 to define an interspace region 107 therebetween. Cathode plate 102 includes a substrate 108, which can be made from glass, silicon, ceramic, and the like. A cathode 110 is disposed upon substrate 108. Cathode 110 is connected to a first voltage source 126. A dielectric layer 112 is disposed upon cathode 110 and defines a charging emitter well 114.

A charging electron emitter 116 is disposed within charging emitter well 114. In the embodiment of FIG.1, charging electron emitter 116 is a Spindt tip electron emitter, which can be made from molybdenum. However, the invention is also embodied by a device having a charging electron emitter that has a geometry other than a conical geometry. For example, the charging electron emitter can be an edge emitter, surface emitter, and the like. It can also be made from an emissive material other than molybdenum, such as diamond, carbon nanotubes, and the like.

Cathode plate 102 further includes a gate extraction electrode 118, which is disposed on dielectric layer 112 and is connected to a second voltage source 127. Application of selected potentials to cathode 110 and gate extraction electrode 118 can cause charging electron emitter 116 to emit electrons.

In the embodiment of FIG.1, cathode plate 102 includes a control electrode 113, which is disposed on dielectric layer 112. Control electrode 113 is connected to a fourth voltage source 129. Control electrode 113 is connected to discharge electron emitter 109 for controlling the potential at discharge electron emitter 109. In the embodiment of FIG.1, discharge electron emitter 109 defines an edge emitter. Discharge electron emitter 109 is made from an electron emissive material. Preferably, discharge electron emitter 109 is made, at least in part, from carbon, most preferably from carbon nanotubes.

Anode plate 104 includes a transparent substrate 120 made from a solid, transparent material, such as a glass. A black matrix 122 is disposed on transparent substrate 120 and is preferably made from chrome oxide. A phosphor 124 is disposed within an opening 123 defined by black matrix 122. Phosphor 124 is cathodoluminescent and emits light upon activation by electrons emitted by charging electron emitter 116.

In general, a discharge electron emitter in accordance with the invention is designed to discharge a charged surface while the voltage at the anode is equal to the operating voltage. Discharge electron emitter 109 is useful for neutralizing first surface 105 of spacer 106. Due to the high operating voltage at anode 125 and by applying a suitable potential to control electrode 113 (e.g., ground potential), discharge electron emitter 109 can be caused to emit a plurality of spacer-discharging electrons 134. The energy of spacer-discharging electrons 134 upon arrival at first surface 105 is low enough to cause discharging, rather than electrostatic charging, of first surface 105. For example, the energy of spacer-discharging electrons 134 upon arrival at first surface 105 can be on the order of 100 volts.

One reason that discharge electron emitter 109 is capable of providing low energy electrons is its greater proximity to spacer 106, as compared to charging electron emitter 116. That is, spacer-discharging electrons 134 are accelerated through a shorter distance than spacer charging electrons 132 and, therefore, have lower energies upon arrival at spacer 106.

Preferably, this proximity is achieved by disposing the discharge electron emitter intermediate the spacer and the charging electron emitter. In the embodiment of FIG.1, this proximity is achieved by disposing discharge electron emitter 109 on spacer 106, such that the emissive surface of discharge electron emitter 109 is coextensive with first surface 105 of spacer 106.

Furthermore, discharge electron emitter 109 is capable of providing an extent of emission that is sufficient to discharge spacer 106 and render it invisible. Sufficient emission current can be provided, in part, by the selection of a sufficiently emissive material, from which discharge electron emitter 109 is made.

The embodiment of FIG.1 provides a diode configuration for the activation of discharge electron emitter 109 to produce spacer-discharging electrons 134. The first electrode of the diode is defined by control electrode 113, and the second electrode of the diode is defined by anode 125. Discharge electron emitter 109 is designed to emit due to the operating voltage at anode 125. The benefit of a diode configuration is that it results in lower spreading of the beam defined by spacer-discharging electrons 134, as contrasted with a triode configuration. Lower beam spreading provides the benefit of a lower rate of generation of contaminants due to portions of the beam being received by non-spacer surfaces.

FIG.2 is a cross-sectional, partial view of a field emission display (FED) 200 having a discharge electron emitter 209, which is a surface emitter, in accordance with another embodiment of the invention. Discharge electron emitter 209 partially defines a cathode plate 202 of FED 200 and is disposed intermediate spacer 106 and charging

An anode 125, which is preferably made from aluminum, defines a blanket layer overlying phosphor 124 and black matrix 122. Anode 125 is connected to a third voltage source 128. Methods for fabricating electron emitters and anode plates for matrix-addressable FEDs are known to one of ordinary skill in the art.

Spacer 106 is made from a dielectric material, such as glass, aluminum oxide (Al_2O_3), and the like. Spacer 106 defines a first surface 105 and a second surface 111. In the embodiment of FIG.1, discharge electron emitter 109 is connected to second surface 111, such that spacer 106 extends between anode 125 and discharge electron emitter 109.

Discharge electron emitter 109 can be made by providing a sheet of the dielectric material from which spacer 106 is made and thereafter depositing on the sheet of dielectric material a layer of nanotube-forming catalyst material, such as nickel, iron, and the like. The sheet of dielectric material having the catalyst layer is then cut into, for example, ribs or other useful geometry. Then, nanotubes are grown in the catalyst layer by using a convenient method, such as chemical vapor deposition employing ethane gas.

During the operation of FED 100, the operating voltage at anode 125 is selected to attract a plurality of charging electrons 130, which are emitted by charging electron emitter 116. Preferably, the operating voltage at anode 125 is high (e.g., greater than 1000 volts relative to charging electron emitter 116). Most preferably, the operating voltage at anode 125 is about 3000 volts. The voltage at control electrode 113 is preferably equal to about ground potential.

One of the benefits of the invention is that the potential at anode 125 can be maintained at the operating voltage during the process of discharging spacer 106. That is, the potential at anode 125 need not be reduced in order to achieve spacer invisibility. The ability to maintain the potential at anode 125 results in benefits, such as reduced power consumption, lower operating costs, and simplified drive electronics.

A portion of charging electrons 130 is received by spacer 106. This portion defines a plurality of spacer charging electrons 132, which are high-energy electrons. For example, the energy of spacer charging electrons 132 at first surface 105 can be greater than about 1000 electron-volts. The energy of spacer charging electrons 132, upon arrival at first surface 105 of spacer 106, is high enough to create positive charges on first surface 105.

The electrostatic charging of first surface 105 is further due to the fact that the secondary electron yield of first surface 105 is greater than 1. The secondary electron yield is defined as the ratio of electrons emitted from a surface to electrons received by the surface.

electron emitter 116. In the embodiment of FIG.2, discharge electron emitter 209 defines an emissive surface 211. Preferably, emissive surface 211 opposes a portion of anode 125 that does not overlie phosphor 124. Discharge electron emitter 209 is made from an electron emissive material. Preferably, discharge electron emitter 209 is made, at least in part, from carbon, most preferably from carbon nanotubes.

Discharge electron emitter 209 can be made by, for example, mixing pre-formed nanotubes with a convenient conductive material, such as, silver, gold, and the like, and, thereafter, depositing and patterning a layer of the mixture on dielectric layer 112. Second surface 111 of spacer 106 is then disposed in abutting engagement with discharge electron emitter 209.

In the embodiment of FIG.2, fourth voltage source 129 is connected directly to discharge electron emitter 209. Similar to the embodiment of FIG.1, the embodiment of FIG.2 defines a diode configuration for the activation of discharge electron emitter 209.

It is known in the art to deposit a layer of compliant metal between a spacer and a cathode plate of a field emission display. The purpose of these prior art spacer pads is to prevent breakage of spacers due to the non-uniformity of spacer height. While these prior art spacer pads may emit some neutralizing electrons, the prior art does not teach or suggest that they emit at a rate sufficient to neutralize the spacer to an extent suitable for realizing spacer invisibility or for preventing excessive distortion of the trajectory of the electrons, which are emitted from the selectively addressed electron emitters. A field emission display in accordance with the invention, on the other hand, does provide a rate of neutralization sufficient to realize at least these benefits.

FIG.3 is a cross-sectional, partial view of a field emission display (FED) 300 having discharge electron emitter 209, which is caused to emit by a triode configuration of electrodes, in accordance with yet another embodiment of the invention. In the embodiment of FIG.3, a cathode plate 302 further includes a discharge emitter gate 321, which is connected to a fifth voltage source 323. A dielectric layer 312 of cathode plate 302 further defines a gate well 325, which allows the potential at discharge emitter gate 321 to act upon discharge electron emitter 209. Discharge emitter gate 321 is disposed to cause extraction of electrons from discharge electron emitter 209. The potential at discharge emitter gate 321 is selected to cause emission from discharge electron emitter 209. Discharge electron emitter 209, discharge emitter gate 321, and anode 125 define the triode configuration for the extraction of spacer-discharging electrons 134 from discharge electron emitter 209.

The triode configuration of FIG.3 provides the benefit of permitting selective control of the spacer-discharging electron current. For example, after the fabrication of

FED 300, one can determine which spacers become charged during the operation of FED 300 and selectively bias for emission only the discharge emitter gates that correspond to the charged spacers. That is, use of the triode configuration becomes necessary to achieve a discharge current, which is high enough to prevent visibility of the spacer. The embodiment of FIG.3 can also provide temporal control. For example, spacer-discharging electrons 134 can be provided continuously or from time to time, such as at the end of each display frame.

FIG.4 is a cross-sectional, partial view of a field emission display (FED) 400 having a discharge electron emitter 409, which is a Spindt tip emitter that is caused to emit when charging electron emitter 116 is caused to emit. A cathode plate 402 of FED 400 has a dielectric layer 412, which further defines a discharge emitter well 411. Discharge electron emitter 409 is disposed within discharge emitter well 411.

Similar to the embodiment of FIG.3, cathode plate 402 of FED 400 has a discharge emitter gate, which is defined by a gate extraction electrode 418. That is, the electrode that causes emission from charging electron emitter 116 also causes emission from discharge electron emitter 409. In this manner, spacer-discharging electrons 134 are provided when they are needed, at those times that spacer charging electrons 132 cause electrostatic charging of spacer 106. Gate extraction electrode 418 is spaced apart from discharge electron emitter 409 and is disposed to cause extraction of spacer-discharging electrons 134 from discharge electron emitter 409.

Similar to the embodiment of FIG.3, FED 400 defines a triode configuration for the extraction of spacer-discharging electrons 134. The triode is defined by discharge electron emitter 409, gate extraction electrode 418, and anode 125. Unlike the embodiment of FIG.3, discharge electron emitter 409 is connected to first voltage source 126, via cathode 110.

Discharge electron emitter 409 is designed to provide spacer-discharging electrons 134 at a rate sufficient to discharge charged first surface 105. For example, discharge electron emitter 409 is made from an electron-emissive material, which can be the material from which charging electron emitter 116 is made. The overall number of discharge electron emitters 409 is also selected to provide a sufficient discharge emission rate.

In general, the energy of each of the discharging electrons is low enough to cause neutralization, rather than electrostatic charging, of the receiving surface. Preferably, each of spacer-discharging electrons 134 is characterized by an energy equal to less than about 100 electron-volts upon arrival at spacer 106. The energy upon arrival at spacer 106 of spacer-discharging electrons 134 is determined, at least in part, by the distance between discharge electron emitter 409 and spacer 106.

The embodiment of FIG.4 further includes a spacer pad 415. Spacer pad 415 is made from a compliant material, such as gold. Electron emission, if any, from spacer pad 415 during the operation of FED 400 is insufficient to neutralize first surface 105 to an extent useful for realizing spacer invisibility. Thus, if discharge electron emitter 409 were absent, first surface 105 would become electrostatically charged to an extent sufficient to result in the visibility of spacer 106.

In summary, the invention is for a field emission display, which has discharge electron emitters. The discharge electron emitters are distinct from the phosphor-activating electron emitters. Furthermore, the discharge electron emitters are configured and designed to provide discharging of dielectric surfaces while the anode voltage is maintained at a high operating voltage value, thereby realizing numerous benefits, such as improved power consumption requirements.

While we have shown and described specific embodiments of the present invention, further modifications and improvements will occur to those skilled in the art. For example, the invention is embodied by a display similar to that shown in FIG.4 and which differs therefrom only in that a carbon surface emitter is substituted for the Spindt tip discharge electron emitter. As a further example, the invention is also embodied by a display similar to that shown in FIG.4 and which differs therefrom only in that the discharge electron emitter is caused to emit by a discharge emitter gate, which can be controlled independently from the gate extraction electrode.

We desire it to be understood, therefore, that this invention is not limited to the particular forms shown, and we intend in the appended claims to cover all modifications that do not depart from the spirit and scope of this invention.

CLAIMS

We claim:

1. A field emission display comprising:

a spacer;

a charging electron emitter; and

a discharge electron emitter disposed intermediate the spacer and the charging electron emitter, wherein the discharge electron emitter comprises carbon.

2. The field emission display as claimed in claim 1, wherein the discharge electron emitter comprises carbon nanotubes.

3. A field emission display comprising:

an anode;

a spacer defining a surface;

a charging electron emitter disposed proximate to the spacer; and

a discharge electron emitter, wherein the spacer extends between the anode and the discharge electron emitter, and wherein the discharge electron emitter comprises carbon.

4. The field emission display as claimed in claim 3, wherein the discharge electron emitter comprises carbon nanotubes.

5. The field emission display as claimed in claim 3, further comprising a discharge emitter gate spaced apart from the discharge electron emitter and disposed to cause extraction of spacer-discharging electrons from the discharge electron emitter; wherein the discharge electron emitter is designed to be connected to a voltage source; and wherein the discharge electron emitter, the discharge emitter gate, and the anode define a triode configuration for the extraction of spacer-discharging electrons from the discharge electron emitter.

6. A field emission display comprising:

a spacer defining a surface;

a charging electron emitter;

an anode disposed to receive electrons emitted by the charging electron emitter, wherein the anode is designed to be operated at an operating voltage, wherein the

operating voltage is greater than about 1000 volts relative to the charging electron emitter, and wherein a portion of the electrons emitted by the charging electron emitter for reception by the anode can cause electrostatic charging of the surface of the spacer to provide a charged spacer surface; and

a discharge electron emitter designed to discharge the charged spacer surface while the voltage at the anode is equal to the operating voltage.

7. The field emission display as claimed in claim 6, wherein the discharge electron emitter comprises carbon.

8. The field emission display as claimed in claim 6, wherein the discharge electron emitter is disposed intermediate the spacer and the charging electron emitter.

9. The field emission display as claimed in claim 6, wherein the spacer defines a second surface, and wherein the discharge electron emitter comprises a layer in abutting engagement with the second surface defined by the spacer.

10. The field emission display as claimed in claim 6, further comprising a discharge emitter gate spaced apart from the discharge electron emitter and disposed to cause extraction of spacer-discharging electrons from the discharge electron emitter; wherein the discharge electron emitter is designed to be connected to a voltage source; and wherein the discharge electron emitter, the discharge emitter gate, and the anode define a triode configuration for the extraction of spacer-discharging electrons from the discharge electron emitter.

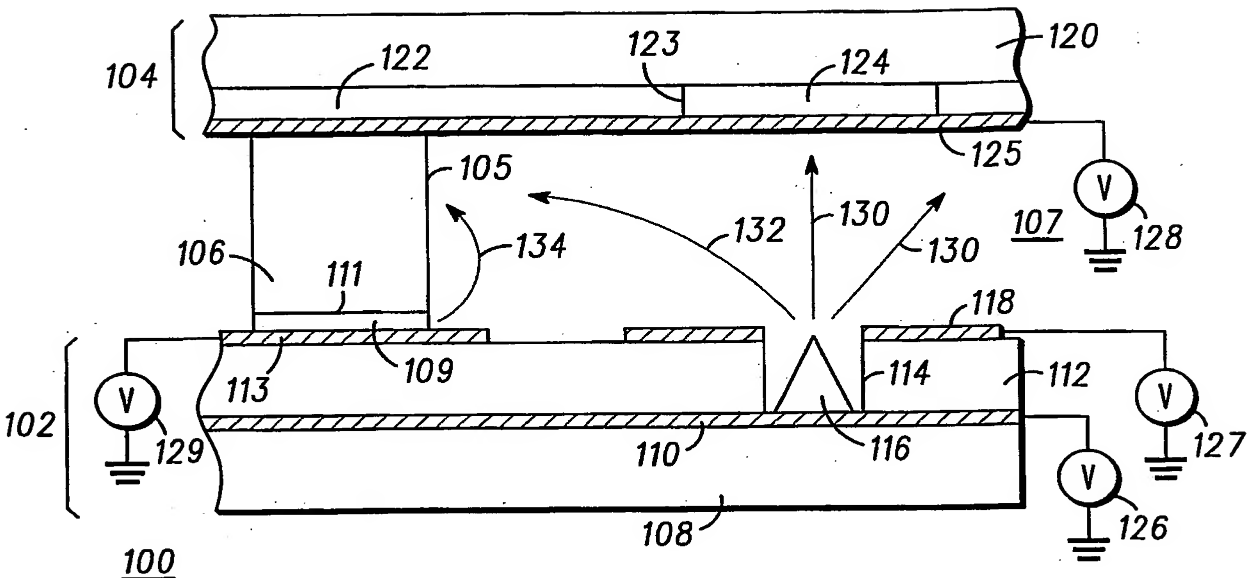

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FIG. 1

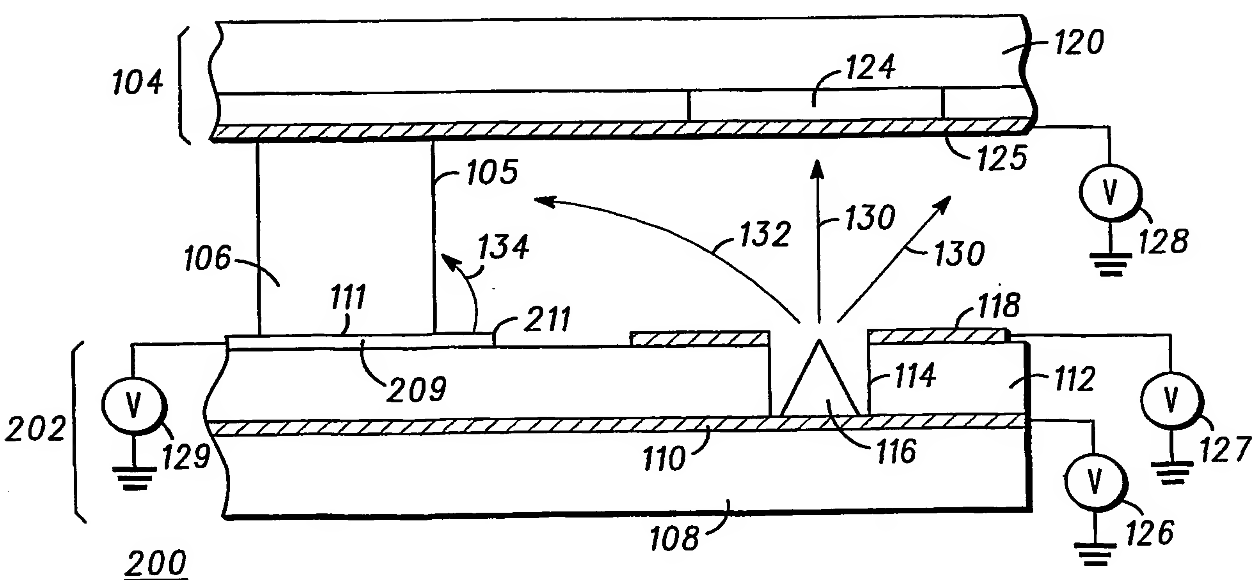

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FIG. 2

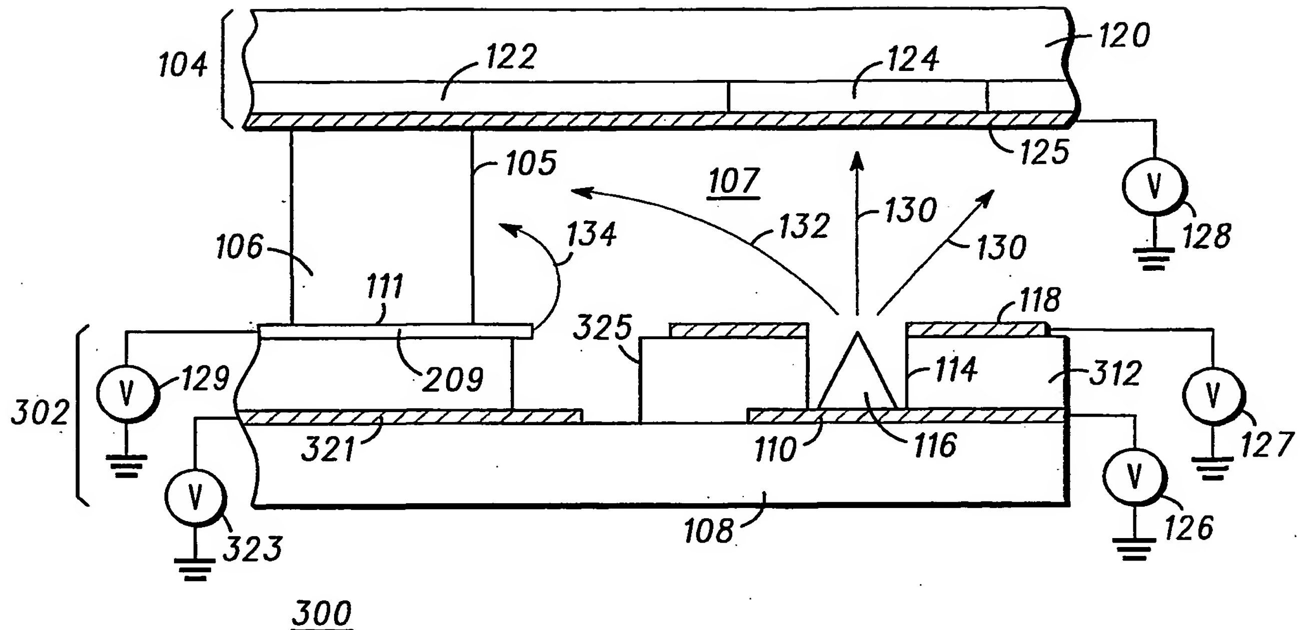
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FIG. 3

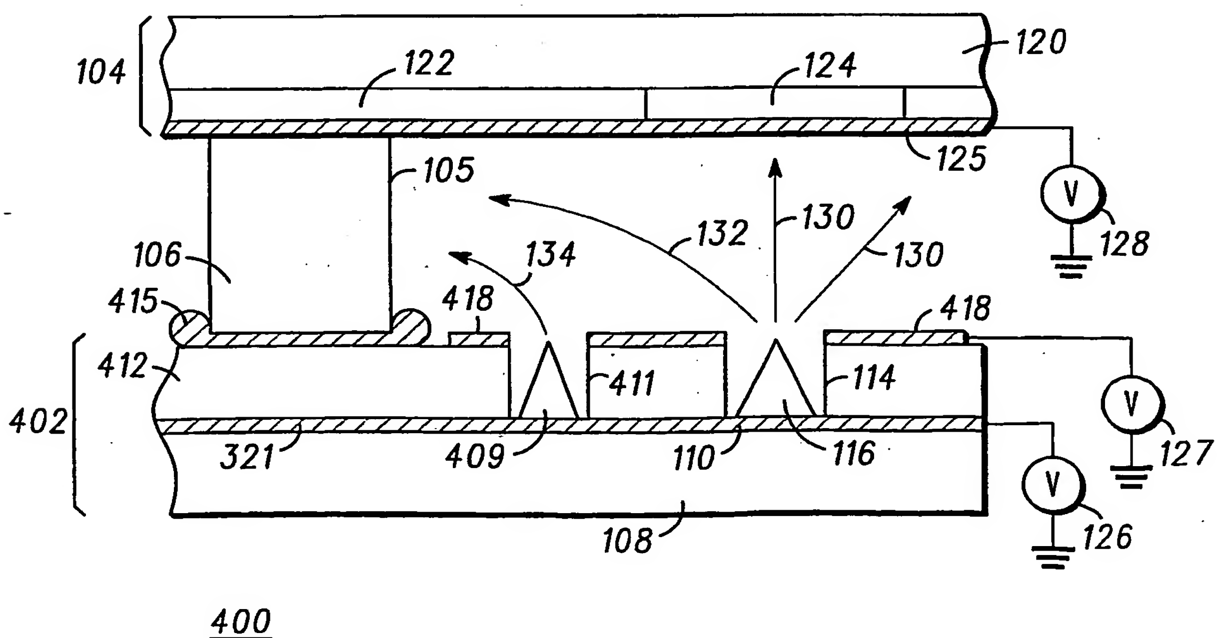
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FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/16666

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01J29/02 H01J31/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01J G09G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, WPI Data, EPO-Internal, INSPEC, COMPENDEX, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 619 097 A (JONES GARY W) 8 April 1997 (1997-04-08) claims 1--14	1
A	WO 99 34390 A (MOTOROLA INC) 8 July 1999 (1999-07-08)	
A	US 6 031 336 A (RUMBAUGH ROBERT C ET AL) 29 February 2000 (2000-02-29) cited in the application claim 1	1
A	US 6 075 323 A (XIE CHENGGANG ET AL) 13 June 2000 (2000-06-13) cited in the application claim 1	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
22 October 2001	30/10/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Van den Bulcke, E

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 01/16666

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